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THE POSSIBLE REUSE OF WASTEWATER TREATED BY LAGOONING FOR THE IRRIGATION OF FIELD CROPS

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ABSTRACT

At the output from the lagooning system in the rural community of Saint-Coulomb, the effluent is of acceptable physical-chemical quality for the purposes of irrigation but care should be taken with regard to the irrigation of boron-sensitive plants. As far as contamination by metals is concerned, the effluent is of the domestic type and can therefore be used without restriction.
Monitoring of effluent quality during the summer months reveals that levels of thermotolerant coliform contamination do not always lie below the value fixed by the C.H.S.P.F. for the irrigation of plants eaten raw (10^4 l^{-1}). However, no intestinal helminth eggs or salmonellaewere detected.
The levels of thermotolerant coliform contamination do not reveal any significant differences (at the 5% level) between plants irrigated with treated wastewater and plants not irrigated at all. Nor is there any significant difference between plants irrigated with standard water (TTC < 10^4 l^{-1}) and sub-standard water. The thermotolerant coliform contamination does not only correspond to contamination by faecal coliforms.

KEYWORDS

Irrigation, pond system, reuse, treated wastewater, vegetables.

INTRODUCTION

The water shortage suffered by certain regions in France since 1989 has led the authorities and managers to look into the possibility of reusing treated wastewater for the irrigation of field crops.

This use, which constitutes an additional treatment of wastewater prior to its return into the natural environment, would also make it possible to preserve the quality of receiving media that have been damaged by the reduction in flow rates.

Since 22nd July 1991, France has had a set of health regulations covering the reuse of treated urban wastewater for the irrigation of crops, parks and public gardens (C.S.H.P.F. 1991a).
In a validation of the W.H.O's approach to the problem, the *Conseil Supérieur d'Hygiène Publique de France* (C.S.H.P.F. Council for Public Hygiene in France) retained parasites as the agents most likely to

constitute a risk of infection following the use of wastewater. Although not totally ignored, the risk of bacterial infection is considered to be less important in relative terms.
Three qualities of treated wastewater have been defined, in line with the uses envisaged (type of plant, irrigation method).

Irrigation water for products which can be eaten raw and for parks or gardens open to the public must not contain more than one intestinal helminth egg (*Ascaris* and *Tenia*) and more than 10^4 thermotolerant coliforms per litre. For other crops and for parks or gardens not open to the public, the quality constraints relate only to parasitic contamination (less than one helminth egg per litre).
In both cases, the maximum values are mandatory under all circumstances (C.S.H.P.F. 1991b).
However, there are no constraints for crops irrigated by methods that introduce a break into the chain of transmission of water-borne risks (subsurface or drip irrigation).

Research into a proposal to reuse treated wastewater in an oceanic climate, within a rural community in which agriculture concerns solely the production of vegetables, seemed to be worthwhile as a field of application for these recommendations.

MATERIAL AND METHODS

Location of the study

The rural community of Saint-Coulomb (*département* of Ille-et-Vilaine, France) is bordered to the North by the shores of the English Channel. The community's sole activity is agriculture; it specialises in the production of field crops (mainly potatoes and cauliflowers).

The permanent population of 1,938 rises to approximately 2,500 during the summer months as a result of the community's proximity to the coast.

Pond system

The sewage plant, which was opened in 1981, uses lagooning to treat the effluent. It includes 4 basins (Fig. 1), the first one being aerated. The basins cover a total area of 7,000 m^2 and contain approximately 9,000 m^3 of sewage water.

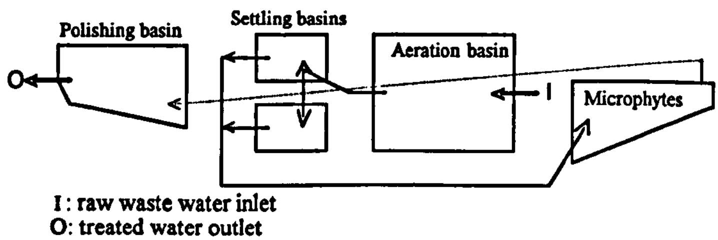

Fig. 1 : Diagram of the treatment plant.

In summer, the input of effluent into the plant reaches its full nominal capacity (2,000 inhab.eq, 120 kg DBO_5 d^{-1}, 300 m^3 d^{-1}).

The period of study

The quality of the treated wastewater was monitored and the irrigation tests were carried out between the beginning of May and the end of July 1992.

Characteristics of the waste water treated.

Physical-chemical composition

In order to check that the water was not likely to damage either soil or crops, tests were carried out to determine the pH, conductivity, and levels of Ca, Mg, Na, Cl and boron. The Na content was determined by flame emission spectrometry; the Ca and Mg contents by atomic absorption. The chlorides were dosed using the Mohr method and boron was monitored by colorimetry (azomethine-H method).

Using a C.S.H.P.F. specification as a reference, the heavy metals contained in the effluent were studied through the contamination of the sludge removed from the various basins (14 sampling points).

The following metals were determined: Cd, Cr, Cu, Pb, Hg, Ni, and Zn. After drying (105°C) and milling (1 μm), the sludge was mineralised with aqua regia in accordance with standard NF X31 151 using flame emission or graphite furnace atomic absorption spectrometry depending on the metal contents. Cold vapour was used for Hg.

Microbiological characteristics

The samples taken on 11th May and 6th July were examined for the presence of helminth eggs.

After decanting (3d, 4°C), the volume of the water sample (25l) was reduced to one-third by siphoning off the supernatant. Given the absence of standardised methods, two extraction methods were then tested. The first one derives from methods used in parasitic coprology. To 33 ml of concentrate from the primary decanting was added 67 ml of Bailenger culture medium. The 100 ml are then distributed between a dozen tubes and, after the addition of an equal volume of ether, the mixture is emulsified and centrifuged (500 g, 5 min).
The centrifuge concentrate is then again placed in suspension in a few drops of saline water and read on the microscope (x100). The count is carried out over a Nageotte cell.

The second method consists of filtering 2 litres of concentrate over a nest of screens with 500, 200, 100, 40 and 20 μm mesh. The three finest screens are pressure-rinsed with distilled water using a counter-current. The 500 ml of rinsing water are then centrifuged twice in succession (500 g, 5 min) and the concentrate is read on the microscope over a Nageotte cell.

In order to assess the efficiency of the two methods during the second count, *Fasciola hepatica* eggs were placed in the sample, using approximately 100 eggs per litre.

An analysis of bacteria (thermotolerant coliforms, faecal streptococci, and salmonella) was carried out on at least one instantaneous weekly sample of effluent. The first five samples correspond to samples taken over a period of 24 hours, grouped at 3-or 5-hour intervals.

The bacteria count was carried out after membrane filtration. The thermotolerant coliforms were grown on TTC and Tergitol 7 lactose agar (44°C, 48 h) and the faecal streptococci over a Slanetz and Bartley culture medium (37°C, 48 h).
The salmonellae were enriched over a Rappaport R10 culture medium (43°C, 24 h) with and without pre-enrichment in peptone water, before being isolated over Hektoën agar (37°C, 24 h). Presumptive colonies were picked and confirmed by subjecting to API-20-E profile analysis.

Inspection of plant quality after irrigation

Crop quality was checked on potato plants and lettuces. The crops that were irrigated received 10 and 20 mm of treated water respectively at any one time. Leaf samples (40 - 60 g) were taken from potato plants 10, 16 and 23 days after irrigation and from lettuces 6 hours, 3 days, 10 days and 33 days after irrigation. On every occasion, samples from potatoes were taken from 5 watered plants and 1 control plant. Samples from lettuces consisted of a mixture of leaves taken from 10 watered plants and 10 plants not irrigated with the treated wastewater.
A sub-sample (10 g) of each sample was made up to 100 g with tryptone saline water homogenised with Ultra Turax.

Bacteria counts were carried out using the most probable number method (MPN), in liquid media with 3 tubes per dilution. Coliforms were isolated in a BCP lactose medium (30°C, 48 h) and positive tubes were reset in a brilliant green lactose medium (44°C, 48 h) to determine the thermotolerant coliforms. Positive tubes were reset in a Schubert medium or peptone water for the Mackenzie test (44°C, 24 h). Faecal streptococci were isolated over a Rothe medium (37°C, 48 h) and confirmed by the further use of a Litsky medium (37°C, 48 h).

RESULTS AND DISCUSSION

Physical-chemical characteristics of the treated water

The variations in the agriculture-related characteristics are shown in Table 1.

Tab. 1 - Agriculture-related characteristics

pH	7.5	-	7.9
Na	129	-	133 mg/l
Ca	78	-	86 mg/l
Hg	15	-	18 mg/l
Cl	132	-	136 mg/l
B	2.75	-	3.15 mg/l

The pH measured lay between 7.5 and 7.9 and is particularly compatible with the use of treated water for the irrigation of cabbages, as brassicas are sensitive to acid pH (club root).

The Na, Ca and Mg levels in the treated effluent give a Sodium Absorption Ratio (S.A.R.) of the order of 3.45. Taken with a conductivity of 920 µS.cm, this S.A.R. value shows that the treated water corresponds, under the U.S. Salinity Laboratory classification of 1969, to an "admissible quality" - but no more. Moreover, Ayers and Westcot (1976) recommend that water containing more than 69 mg/l of Na and 106 mg/l of Cl be used very sparingly. In the present case, the values measured are 130 and 134 mg/l respectively. The water is, therefore, suitable for the irrigation of crops which are salt-tolerant, on well drained soils.

The 7 values taken for boron, of between 2.75 and 3.15 mg/l, would appear to be slightly higher than those indicated for urban effluent (Guillot, 1980). These high results can no doubt be explained by the effect of the sea on the boron-containing rainwater and other rain containing Na and Cl.

According to Pettygrove and Asano (1985), although lettuce and brassicas, which are moderately tolerant to boron (phytotoxic), will stand boron contents of between 2 and 4 mg/l, potatoes only tolerate concentrations of between 1 and 2 mg/l. There is, therefore, a need to pay particular attention to boron, especially in coastal areas.

The heavy metal contents of the sludges are shown in Table 2.

Tab. 2 - Heavy metal contents of the sludges in ppm of dry matter

Cd	1	-	<1
Cr	52	-	20
Cu	110	-	18
Zn	276	-	57
Ni	55	-	45
Pg	13	-	5
Hg	1	-	0.5

In accordance with existing publications (Suffern et al. 1981, Carré et al 1986), these levels are low and this characteristic is further emphasised by the absence of industry and the size of the rural community.

The low metal contents in the sludge indicate that the wastewater is indeed domestic in origin and that it should therefore be suitable for use, without restriction, as far as the elements tested are required.

Microbiological characteristics

The two parasitological studies carried out did not reveal the presence of any helminth eggs (*Teania, Ascaris, Trichuris, Enterobius*) in the water at the output from the lagoon.
This absence of contamination may be explained in two ways. Firstly, the methods used for the count are not efficient unless there is a high number of eggs. The Teichmann method quoted by Mara and Cairncross (1988), for example, is 70% efficient for 100 eggs per litre but only 30% efficient for 1 egg. The efficiency rating for the two methods used in this study was only 37% (Bailenger) and 47% (filtration) for 100 *Fasciola hepatica* eggs per litre, these eggs being larger in size than *Ascaris* or *Tenia* eggs. The low efficiency of the methods is probably not the only explanation for the absence of helminth eggs in the treated water. The long period during which the water remained in the sewage plant (theoretical time: 30 days in this instance) results in the eggs being retained in the sludge at the bottom of the basins. This being so, the detection of helminth eggs as required under CSHPF regulations (CSHPF 1991b) every fortnight throughout the year prior to use and during the first year of application of the water is of little consequence for water supplied from a lagoon in which it has already been stored for some considerable time.

Figure 2 shows the extent of contamination from thermotolerant coliforms and faecal streptococci in water at the output from the lagoon between 5th May and 29th July.

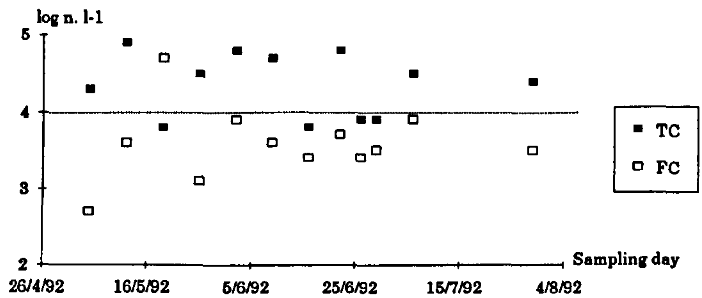

Fig. 2 : Concentrations of thermotolerant coliforms and faecal streptococci in effluent.

For the first 5 samples taken, the result is the geometric mean of the levels of contamination on hourly samples taken over a period of 24 hours. The other points refer to instantaneous samples. The contamination by thermotolerant coliforms lies between $6.2.10^{3}$ and $7.2.10^{4}$ C.F.U. l^{-1}.
Of 12 samples, only 4 show contamination levels of less than 10^{4} C.F.U. l^{-1}. This is the maximum value for unrestricted irrigation under C.S.H.P.F. recommendations.
The values observed for thermotolerant coliforms but also for faecal streptococci are higher by 0.5 to 1 C.F.U. l^{-1} than those reported earlier by Demillac et al (1987) on a natural lagooning system in a climatically-equivalent context and than those foreseeable for a lagooning system with 4 basins, but in a Mediterranean climate, according to Rodier and Brissaud (1989).
The climatic conditions during the research period (temperatures slightly above the seasonal normal, slightly lower-than-average sunshine at the beginning of July) do not explain the high values for thermotolerant coliforms.
It is probably the rise in effluent levels up to the plant's nominal capacity during the summer period and the fairly short time that the effluent spends in the first basin which are the principal causes of these mean results.

By monitoring the quality of the water for 24 hours during the first 5 samplings (Fig. 3), it was shown that contamination by thermotolerant coliforms fluctuated by approximately 1 Ulog depending on the time of sampling and the day, without any apparently logical reason for the difference.
The variations in the rate of input into the sewage plant and differences in hours of sunshine may explain the fluctuations.

The levels of contamination by thermotolerant coliforms may, therefore, be lower than 10^{4} C.F.U. l^{-1} and the water could then be used for irrigation without restriction at one time whereas it would not be suitable for this purpose at another.

Moreover, even in the case of a recently-opened and well designed ponds system of the correct size, Demillac et al (1987) has shown that, in an oceanic climate, the contamination levels of treated water are not kept constantly below 10^4 thermotolerant coliforms per litre. Indeed, this is impossible whatever the type of sewage plant without increasing the disinfecting to which the water is subjected.

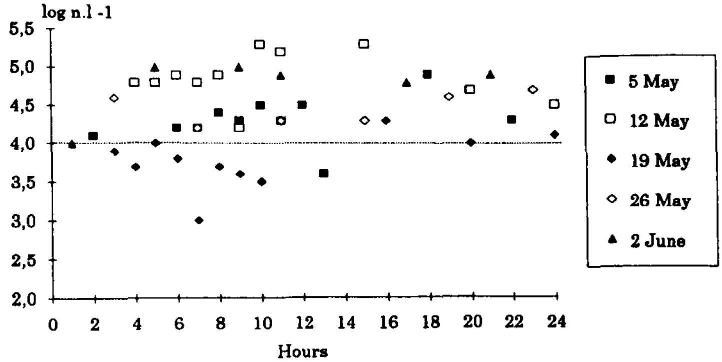

Fig. 3 : Concentrations of thermotolerant coliforms in effluent.

The study did not reveal the presence of any salmonella. Suspect colonies grown on a Hektoën agar plate and identified on an API gallery corresponded to *Citrobacter freundii*, *Chromobacterium sp.*, *Proteus mirabilis*, and *Proteus vulgaris*.

The frequently-observed link (Geldreich and Bordner, 1971) between contamination levels in excess of 10^4 thermotolerant coliforms per litre and the presence of salmonella has not, therefore, been verified in this case.

Quality of the plants irrigated with treated water

In the absence of any microbiological standards for freshly-picked vegetables, it seemed to be worthwhile assessing the level of contamination that could be associated with irrigation using treated wastewater.

The level of contamination by thermotolerant coliforms in the irrigation water was equal to $5.5.10^4$ C.F.U. l^{-1} in the test on potatoes (sub-standard water) and 8.10^3 C.F.U. l^{-1} (standard water) in the test on lettuces.

Figure 4 shows the contamination revealed on irrigated and control potato plants.

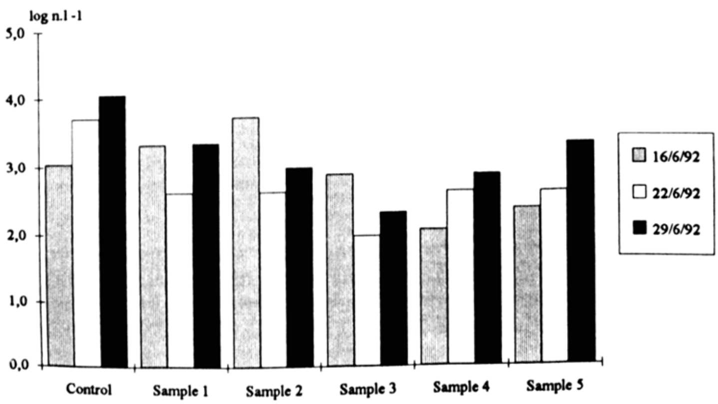

Fig. 4 : Concentrations of thermotolerant coliforms on potato plants.

The contamination levels found on samples taken on any one day are very similar.

Surprisingly, the control contamination levels are higher than the levels found on irrigated vegetables. By using the confidence-interval supplied by the MPN tables for a 0.05 risk, it is not possible to show the existence of any difference in contamination levels between the control product and samples 1, 2, 4 and 5 sampled 2 weeks after watering, between the control product and samples 1, 2 and 5 taken 3 weeks after watering, or between samples of the same rank at the three sampling dates.

The levels of contamination by thermotolerant coliforms revealed in lettuce leaves are shown in Table 3.

Tab. 3 - Thermotolerant coliforms on lettuce leaves

Date of sampling	26/6	29/6	6/7	29/7
Control	5.10^3		9.10^3	4.10^3
Irrigated lettuce	2.10^4	2.10^3	2.10^4	2.10^3

As in the previous test, the control product is also contaminated with thermotolerant coliforms. However, the level is lower than that measured on the sample taken from among the irrigated lettuce (1 log).

A comparison of the MPN confidence interval markers for a 5% risk does not reveal any conclusive evidence of differences in contamination between the control products and the sample, whatever the date, between the control products at different dates, between the samples irrigated from one sampling date to the next, and between the control products and the samples irrigated at all dates.

A Mackenzie test was carried out on various control and irrigated samples (Table 4).

Tab. 4 - Identification of thermotolerant coliforms

		Th. coli.	*E.coli*
Potatoes	Control 29/6	1.10^4	5.10^3
	Sample 29/6	7.10^2	7.10^2
Lettuce	Control 6/7	9.10^3	2.10^3
	Sample 6/7	2.10^4	2.10^4

This test shows that the designation "thermotolerant coliforms" covers a large number of what are presumed to be *Escherichia Coli*, which are also found on control products.

The identification of the supposed *E.Coli* over an API gallery shows that the plants have been contaminated not only with *E. Coli* but also with Klebsiella (*K. pneumoniae*, *K. oxytocae*, and *K. ozaenae*). This last genus is present in both wastewater and in the environment. Its presence, which may explain the fairly high levels of contamination in the control products during both tests, makes it more difficult to interpret the results in health terms, especially inasmuch as this type of identification is very rarely asked for.

CONCLUSION

The research carried out as a preliminary to the reuse, for irrigation purposes, of wastewater treated by lagooning in the rural community of Saint-Coulomb shows that, as far as contamination by metals is concerned, the water does not pose any specific problem. Given the characteristics of the agricultural environment, the water can be considered as suitable for use in farming. However, particular attention should be paid to the boron content if the water is to be used for the irrigation of boron-sensitive plants such as potatoes.

Monitoring of the bacteriological quality over the most favourable climatic period shows that the treated water does not always meet C.S.H.P.F. recommendations with regard to thermotolerant coliform ($<10^4$ l^{-1}) values. Theoretically, then, it is not advisable to use the water on plants that can

be eaten raw, such as lettuce or cauliflowers. The identification of the thermotolerant coliforms present on the plants studied shows that, although some of them are indeed *E. coli*, some correspond to other genera, including Klebsiella.
These results provide another argument against approaching a health risk in terms of a thermotolerant coliforms.

Finally, given crop-growing practices, the distinction between plants that can be eaten raw and others is not always the most appropriate means of differentiation.
The study shows, indeed, that cauliflowers are only irrigated in the Saint-Coulomb area during sowing and pricking out, i.e. long before the formation of the head which is actually eaten.

The recommendations put forward by the C.S.H.P.F. are praiseworthy inasmuch as they lay down a framework for reflection prior to any project aimed at the reuse of treated wastewater.
New knowledge, which is required in particular with regard to the helminth egg count or the importance of the thermotolerant coliforms should make it possible to refine these recommendations still further.

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